BIM Enabled Approach for Performance Based Design: Process, Renewable Technology, Design Rules and Assessment

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ABSTRACT

Significant amount of energy is consumed by buildings due to ineffective design decisions with little consideration of energy efficiency. Yet, performance parameters should be considered during the early design phase, which is vital for improved energy performance and lower CO_2 emissions. BIM, as a new way of working methodology, can help for performance based design. However, it is still infancy in architectural practice about how BIM can be used to develop energy efficient design. Thus, the aim is to propose a strategic framework to guide architects about how to do performance based design considering the local values and energy performance parameters. The research adopts a multi case study approach to gain qualitative and quantitative insights into the building energy performance considering the building design parameters. The outcome is a new design approach and protocol to assist designers to successfully use BIM for design optimization, PV technology use in design, rules-based design and performance assessment scheme reflecting local values.

Keywords: Building information modelling, Design Optimisation for Energy Efficiency, Building Performance, Energy Analysis, BIM based Design Approach.

1. INTRODUCTION

Buildings' energy consumption has significantly increased recently. This is due to the growth of population, increased time spent indoors, more request for indoor environmental quality and for building functions, and finally global climate change (Cao et al., 2016). Energy efficient building is seen as a solution to energy scarcity and CO_2 emissions. However, it is still not adopted totally in building design as a strategy, e.g. in Turkey. This necessitates the consideration of building design criteria as they strive towards protecting nature at the highest possible level and providing the most suitable environment for people within building (Gür, 2007).

The energy consumed by buildings in Turkey is 175 KWh/m2. While in European countries, the amount of energy used is around 100 KWh/m2 (Kazanasmaz et al., 2014). This is greatly due to the inefficient building design with hardly any consideration of the environmental impact and energy assessment (Mangan and Oral, 2016). It is necessary to ensure efficient energy use in Turkey because buildings are responsible for around half of the total energy consumption (Eskin & Türkmen, 2008). Design parameters should be studied, taking into consideration the environment that is a vital for developing a well-suited and energy efficient building design.

There are several design factors that can influence the building energy performance and can be managed properly for better energy efficiency. Enhancing the thermal performance of the envelope materials will lead to the less building energy consumption. The envelope materials work as a promising solution for both less energy consumption and better indoor environment (Han & Taylor, 2016). They can be enhanced by decreasing the thermal transmittances (U-value) combined with the passive energy actions (Cao et al., 2016). Appropriate shading design and selections are important to achieve energy efficiency and comfortable indoor environments. Proper design of overhangs shading systems will play a great role in reducing the unnecessary solar gains in buildings (Ali and Ahmed, 2012).

As cited by Cho et al. (2012), building location plays an important role in designing energy efficient buildings and it is usually considered in the design of new buildings. The building shape can also lead to energy efficiency. For instance, compact building shape will have minimum heat losses through its envelope materials and decreased exposure of weather conditions than complex building shape. This is due to the decreased surface area exposure (Bauer et al., 2009).

The ability that a building must naturally heat or light its internal spaces may significantly influence energy efficiency and reduces energy use. This is often measured by building orientation (Abanda and Byers, 2016). The application of renewable energy will not only lead to further modernization of the energy sector, but also achieve national economic and sustainable development goals (Inglesi-Lotz, 2013). Renewable energy can ensure the sustainability of electricity supply while reducing carbon dioxide emissions (Sulaiman et al., 2013).

Presently, the design and construction practices do not allow the timely and active application of energy efficient methods and technologies on buildings. (Cho et al., 2012, Arayici et al 2018). In this regard, building performance simulation enables designers to investigate various design alternatives and choose the most energy efficient alternatives (Aksamija, 2013). The use of BIM in building energy simulations has deeply enhanced the process of building energy analysis allowing for better decision making and appropriate prediction of building performance.

Bahar (et al., 2013) mentioned that, presently there is a high request for high-performance buildings. That is why, BIM based energy analysis is greatly required because BIM can allow the use of reliable and well organized information about building and it enables improved forecasting and decision making about the building performance. The main question of this study is "*what should be the approach for the performance-based design and optimization through the BIM use?*".

The next section accumulates the literature findings to scope for a performance based design approach.

2. SCOPING FOR A DESIGN APPROACH

Achieving sustainable and efficient building design performance, critical design decisions should be made by the stakeholders at the design stage of a building. Building Information Modelling (BIM) can be used for energy and performance simulations, where the analysis process can be integrated with the design process. However, *the main issue in implementing performance-based design is how to successfully combine various technologies that exist in various domains and deliver complete performance analysis of the building in a collaborative manner during the design process.* The absence of integration in the design process leads to an incompetent design process (Cho et al, 2012). This is due to fact that BIM paradigm greatly requires collaboration between various stakeholders (Jeong and Kim, 2016; Arayici et al 2018).

BIM design and energy analysis software are currently different and necessitate exchanging of data and information (Aksamija, 2013). Methods for information exchanges between BIM and energy analysis software are mainly dependent on the purpose of the analysis and what type of information is needed.

Sustainable design looks for lowering energy consumption, decreasing the negative impacts on environment, and ensures comfort for building occupants (Abdelhameed, 2017). Thus, ecological building design criteria should be considered in the building design (Omrany and Marsono, 2016).

Ecological building design includes materials reflecting local environment, reducing energy consumption to minimum, using local and renewable resources instead of natural sources, creating healthy indoors and natural lighting (Gultekin and Alparslan, 2011). Therefore, use of the ecological strategies for building design by considering the local environmental conditions can be a promising way to ensure efficient building performance.

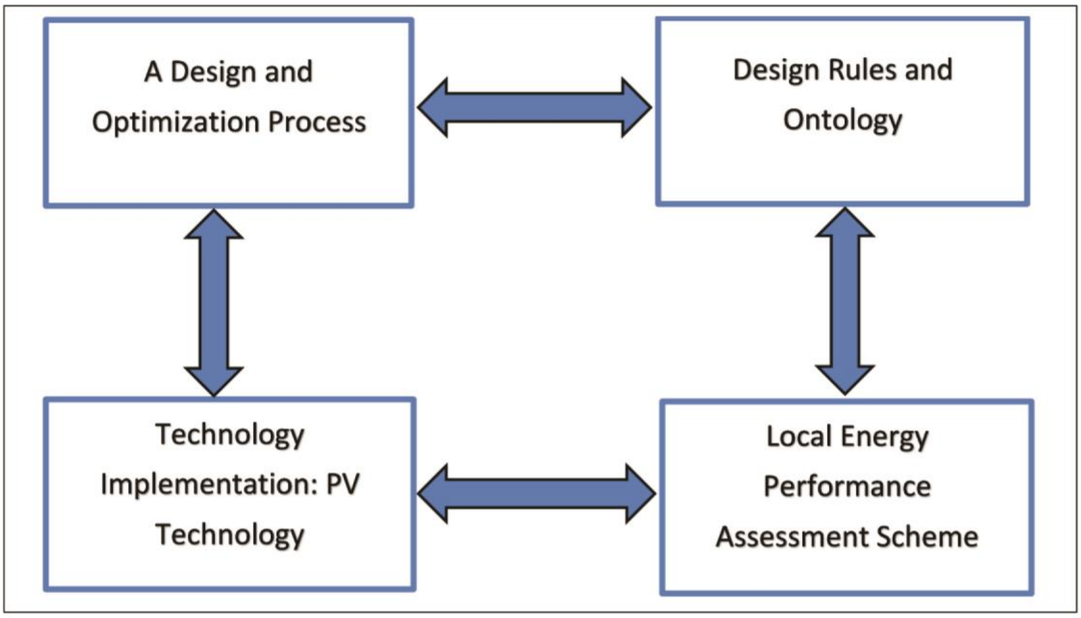
Renewable energy technologies can greatly ensure sustainable electricity supplement and reduce carbon dioxide emissions (Sulaiman et al., 2013). Turkey's energy and environmental problems caused by the increase in building energy use, necessitate the implementation of renewable and energy efficient strategies in the building sector. Thus, encouraging the use of renewable energy such as photovoltaic for energy generation will be a key measure to address energy-related challenges and address sustainability issues (Mangan and Oral, 2016).

Recently, the use of energy rating procedures for assessing buildings is becoming increasingly important. There are different building assessment certificates such as (LEED), (BREEAM) and Green Star (Roderick et al, 2008). All of these schemes are based on rating systems that are applied to many of building types, including new and existing buildings. Mainly, these rating schemes cover a range of environmental issues such as materials, energy, water, pollution, indoor environmental quality and construction sites. The most important credit for all schemes is the energy consumption or carbon emission.

Energy scheme and certificate can provide a wide range of information about the building performance with rating itself (Arkesteijn and van Dijk 2010). However, there is a consensus that global certification of green building is not possible due regional differences in environment conditions, supply of energy, raw material, water, availability of green materials, and economic conditions (Ilter and Ilter, 2011). Thus, developing an energy performance assessment scheme considering the local design criteria and conditions is highly needed.

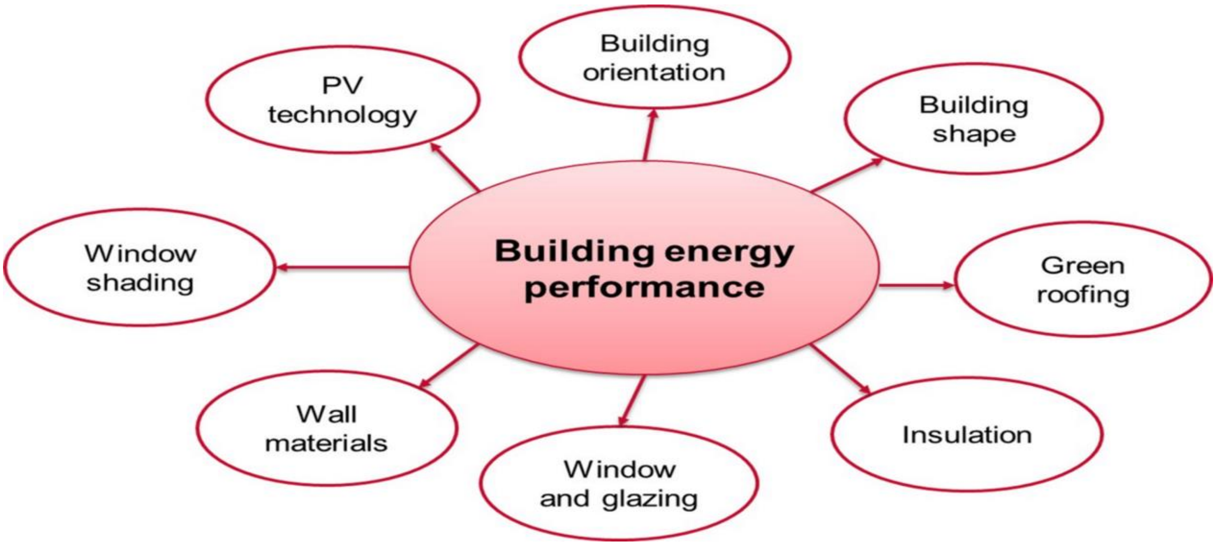
Based on the facts in the literature above, an overall conceptual framework is proposed as shown in Figure 1 with four key dimensions: i) design and optimization process, ii) renewable technology implementation (PV), iii) Design rules and Ontologies, iv) Local Energy Performance Assessment Scheme.

Figure 1. The conceptual scope for the BIM based design and optimization



The conceptual framework shown in Figure 1, represents a design approach with BIM use for the purpose of design optimization and achieving energy efficient building. Regarding the key components in Figure 1, key factors from literature are identified, shown in Figure 2, for performance based design and optimization (Cao et al., 2016; Ali and Ahmed, 2012; Bauer et al., 2009; Abanda and Byers, 2016; Sulaiman et al., 2013).

Figure 2. Key factors considered for building performance analysis



In the next section, the research methodology of the paper for the substantiation of the design approach in Figure 1 is explained.

3. RESEARCH METHODOLOGY

The main research question of this study is "what is the design approach for the performance-based design and optimization with BIM?" and the subsequent sub-questions are as follows:

1. How building design can be optimized to decrease energy consumption by using BIM in the design process?
2. Which design components would better affect the energy performance of a building?
3. What are the passive design strategies that would lead to energy efficient buildings?
4. To what degree would the combination of building design strategies provide energy saving?

The BIM based strategic framework is developed for performance based design and optimization via experimental research on the case study projects in Turkey. Multiple case study research is adopted that helps gain in-depth analysis since other approaches such as survey, interviews or even observations would not be sufficient to carry out accurate analysis and examination of the key factors considered in Figure 2, stimulated from the four components of the initial scoping conceptual framework in Figure 1.

The experimental case study approach is considered as the most appropriate approach to investigate those key factors in Figure 2 because of its features that can handle all the challenges sat by the research questions and objectives. This strategy also allows focusing on the research question and going deep in investigations. Moreover, the flexibility needed in this study can be achieved by using this method as it deals with many types of questions such as what, which, and how questions and to build quantitative and qualitative data (Saunders et al, 2009). Thus, the four main components of the conceptual scoping in Figure 1 are examined on the different case studies, shown in Table 1.

Table 1. Shows which components of conceptual scoping are analysed in which case studies

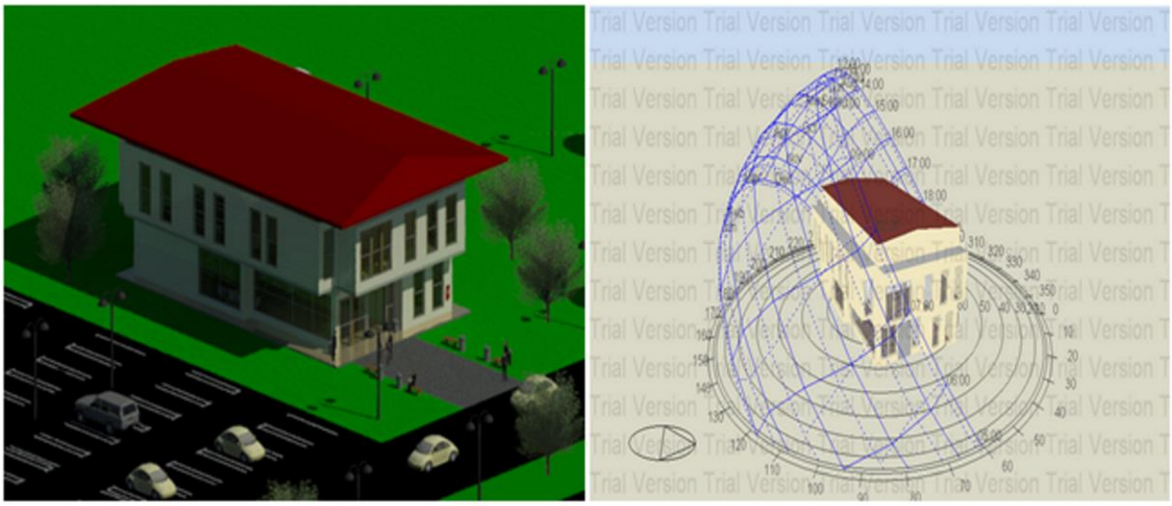
	Design Process Optimization	**PV technology Optimization**	**Design Rules & Ontology Spec.**	**Energy Performance Assessment Scheme**
ARBIM Case Study Building	Yes	Yes	No	No
Passive House Case Study	No	No	Yes	Yes
Health Science Building	Yes	Yes	Yes	Yes

The first two components (design optimization process and PV technology implementation) were studied on the ARBIM (Smart Referential Building and Innovation Centre) case study building. While, the other two components (design rules and ontology and local energy performance assessment scheme) were studied on the Gaziantep Ecological (passive house) building. Finally, for the purpose of validation of the framework as a whole, the newly built Health Science Building in the University campus was used. Revit platform is used for BIM modelling while Design Builder platform is used for the energy performance analysis in relation to the key factors illustrated in Figure 2.

4. CASE STUDY 1: THE ARBIM BUILDING

The first case study building is examined to specify the key factors and related measurable design parameters, modelling and data exchange, analysis process and results. The building is a two-storey university building located in Gaziantep, Turkey. Figure 3 shows the BIM model and the performance analysis model.

Figure 3. BIM model for the ARBIM building case study model



4.1 Findings from Case Study 1 (The ARBIM Building)

Initial iteration for the two components (design optimization process, and PV technology) is carried out. Factors shown in Figure 2 such as building orientation, wall insulation, windows and glazing and PV installations are analysed. For example, the actual orientation of the building is at 330 degrees, where the front side of the building is facing north-east direction. To determine the optimum orientation, 12 other tests were simulated, by rotating the building 30 degree at each test, shown in Table 2.

Table 2. The impact of building orientation on building energy consumption

Orientation	Annual cooling load (KWh)	Annual heating load (KWh)	Annual energy load (KWh)	CO_2 Emission (Kg)
(330) actual	34903.88	13221.09	48124.97	25992.13
(0) optimum	33594.34	12577.04	46171.38	25334.10
30	35588.92	12913.98	48502.9	26152.28
60	37957.7	13184.42	51142.12	27084.9
90	38551.1	13144.7	51695.8	27286.26
120	38539.01	13447.72	51986.73	27369.56
150	36590.23	13297.95	49888.18	26622.25
180	34357.25	13067.00	47424.25	25748.56
210	35472.36	13631.00	49103.36	26313.65
240	36978.67	13933.47	50912.14	26943.82
270	37102.86	13671.95	50774.81	26912.54
300	36801.23	13690.12	50491.35	26810.73

As shown in Table 2, the energy use of building at its actual direction will make an annual energy consumption equal to 48124.97 KWh and annual CO_2 production equal to 25992.13 kg, while the building is at (0) degree direction will perform the best in energy efficiency, making an annual energy use equal to 46171.38 KWh and annual CO_2 production equal to 25334.10 kg. The implementation of the optimized building orientation would lead to energy saving equal to 1309.54 KWh and 644.05 KWh for cooling and heating respectively, and reduction in CO_2 emission equal to 658.03 Kg. As a result, (0) orientation, which is the best orientation means that the building should be designed in a way, where the building long length walls should be facing north-south orientation and the bigger glaze area should be stored on the long length walls facing south.

In terms of building window glazing, the type of glazing used for the actual building design is clear double glazed 4mm with air gap equal to 12 mm. To examine the influence of glazing on building energy use, different glaze thicknesses and types are simulated and analysed. The simulation results are shown in Table 3.

Table 3. The impact of glazing types and thickness on building energy consumption

Glazing type	U value (w/m2.k)	Heating energy load (KWh)	Cooling energy load (KWh)	Total energy load (KWh)
Double 4mm clear-12 air gap	2.866	13221.09	34903.88	48124.97
Double 4mm low e-12 air gap	1.771	13069.39	29563.33	42632.72
Double 6mm clear-12 air gap	2.823	13568.49	33655.08	47218.57
Double 6mm low e-12 air gap	1.754	13346.00	28695.30	42041.30
Double 6mm tinted-12 air gap	2.828	16665.6	25646.70	42312.30

As shown in Table 3, the use (6mm double low e) glazing will perform the best and lead to the lowest energy consumption when compared to the other types, making an annual energy consumption equal to 42041.30 Kwh and annual CO_2 production equal to 23781.77 Kg. This is due to its low U value of 1.754, which describes the flow of heat from wormer place to cooler place. Less U value means less energy loss and less CO_2 emission. The use of 6 mm low e-glazing leads to annual energy saving equal to 6083.67 Kwh and annual reduction in CO_2 emission equal to 4547.22 kg when compared to the actual glazing used in the building.

In terms of wall insulation, the most commonly used types in Turkey are considered and analysed, which are: Expanded Polystyrene Foam (EPS), Extruded Polystyrene (XPS) and Rock Wool (RW) (Uygunoğlu et al., 2016). The analysis results are shown in Table 4.

Table 4. The Impact of Wall insulation on the building energy performance

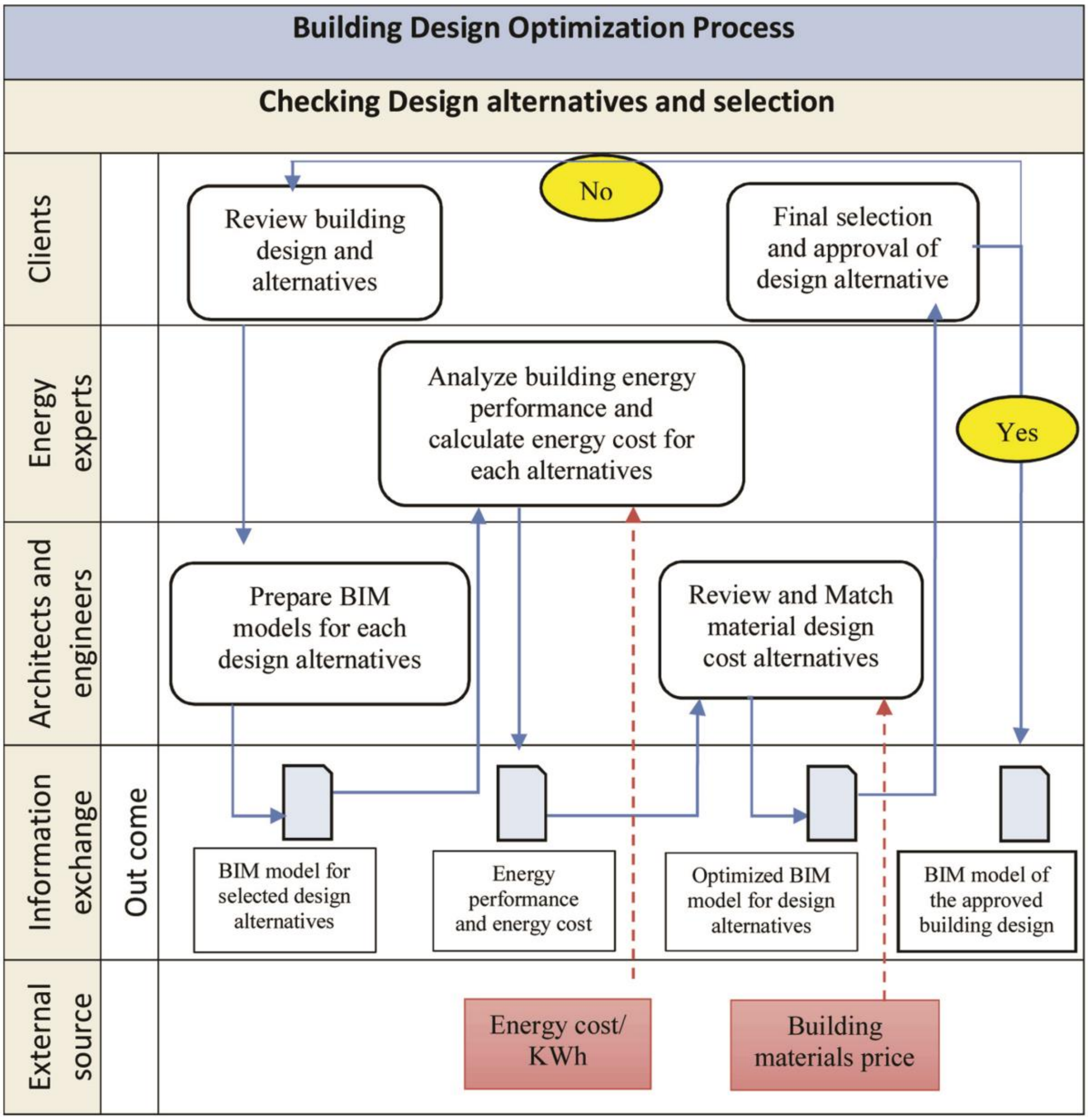
Insulation type (4 cm)	U-value (w/m2. k)	Heating load (Kwh)	Cooling load (Kwh)	Annual energy load (Kwh)	Co2 emission (Kg)
No insulation (actual)	0.897	13221.09	34903.88	48124.97	25992.13
Rock wool	0.509	10628.14	35290.85	45918.99	25278.80
Extruded polystyrene	0.408	10074.89	35304.96	45379.85	25124.36
Expanded polystyrene	0.473	10433.73	35290.46	45724.19	25222.61

All the insulation materials have an impact on the building energy performance (Table 4). The use of (XPS) has the best impact on the heating energy use compared to the other types, making annual energy consumption equal to 45379.85 Kwh and annual CO_2 emission equal to 25124.36 Kg, which is the lowest. This is greatly because of its low U-value, which determines the flow of energy from wormer places to cooler places. In other words, the less U value will lead to less energy consumption.

4.1.1. A Design Optimization Process

To optimize the building performance, an early collaboration is highly needed between the actors at the early design stage. For instance, designers and engineers need to know what type of materials to use for a specific design. This can be done through reviewing the available materials with clients, who will decide on which one to be used based on different aspects such as energy performance, economy and aesthetic needs. The analysis on the ARBIM building, design process should be as shown in Figure 4 that reflects an integrated process for performance-based design.

Figure 4. Stakeholders and Design process stages and tasks



The proposed workflow starts with the clients receiving the energy performance of the actual building model and suggesting alternatives in a collaborative manner with architects based on the materials availability, economic and aesthetic needs. Architects would then develop design alternatives and prepare them for energy analysis. Selected design alternatives would be transferred to the energy expert to conduct performance analysis and simulation for each alternative for their energy performance and cost.

The analysis results will be handed over to architects and engineers, who will also calculate the cost of each design alternatives and make some changes on building design based on the energy performance, energy cost and materials cost for each design alternative. Lastly, the design alternatives will be shared with client, who would then choose the best one based on economical, energy efficient and aesthetic needs.

4.1.2. Technology Implementation (PV Technology)

Dos Santos and Rüther, (2012) stated that optimizing the performance of PV systems installed on buildings, the orientation of PV arrays and PV's tilt angles are the main parameters. Different orientations and tilt angles of PVs are tested and simulated for the ARBIM building. PV systems applied on the roof is calculated to analyse the energy performance of PV systems. The type of PV technology used is called crystalline silicon (c-Si), installed on a pitched roof structure. The area of PV array is equal to 2.92 m2. The simulation results of the impact of PV orientation, tilt angle and row distance on PV performance are presented in table 5, 6 and 7.

Table 5. The impact of orientation on PV performance

PV orientation	PV array area (m2)	Electricity generated (KWH)	Electricity generated/consumed (%)
North	2.92	533.19	3.44
North-east		637.06	4.11
East		830.25	5.36
East-south		983.44	6.35
South		1046.31	6.76
South-west		1003.35	6.48
west		816.55	5.27
West-north		663.14	4.28

The annual generation of PV system for eight different directions is calculated (Table 5). PV array facing the south orientation makes the maximum electricity generation, which is equal to (1046.31) and satisfies 6.76% of the total electricity consumed by the building.

Table 6. The impact of tilt angle on PV performance

The tilt angle of PV array	PV array area (m2)	Electricity generated (KWH)	Electricity generated/electricity consumed (%)
0	2.92	946.87	6.11
10		1006.64	6.5
20		1045.29	6.75
30		1062.19	6.86
40		1057.14	6.83
50		1030.39	6.65

As shown in Table 6, the optimum tilt angle for the PV array is at angle of (30) degree, which makes an annual electricity generation equal to 1062.19KWh and it satisfies around 6.86% of the total electricity consumed in the building.

As shown in Table 7, the row distance of 0.5m makes the lowest energy generation. This is mainly due to the partial shading caused by the self-shading of PV array rows over the other.

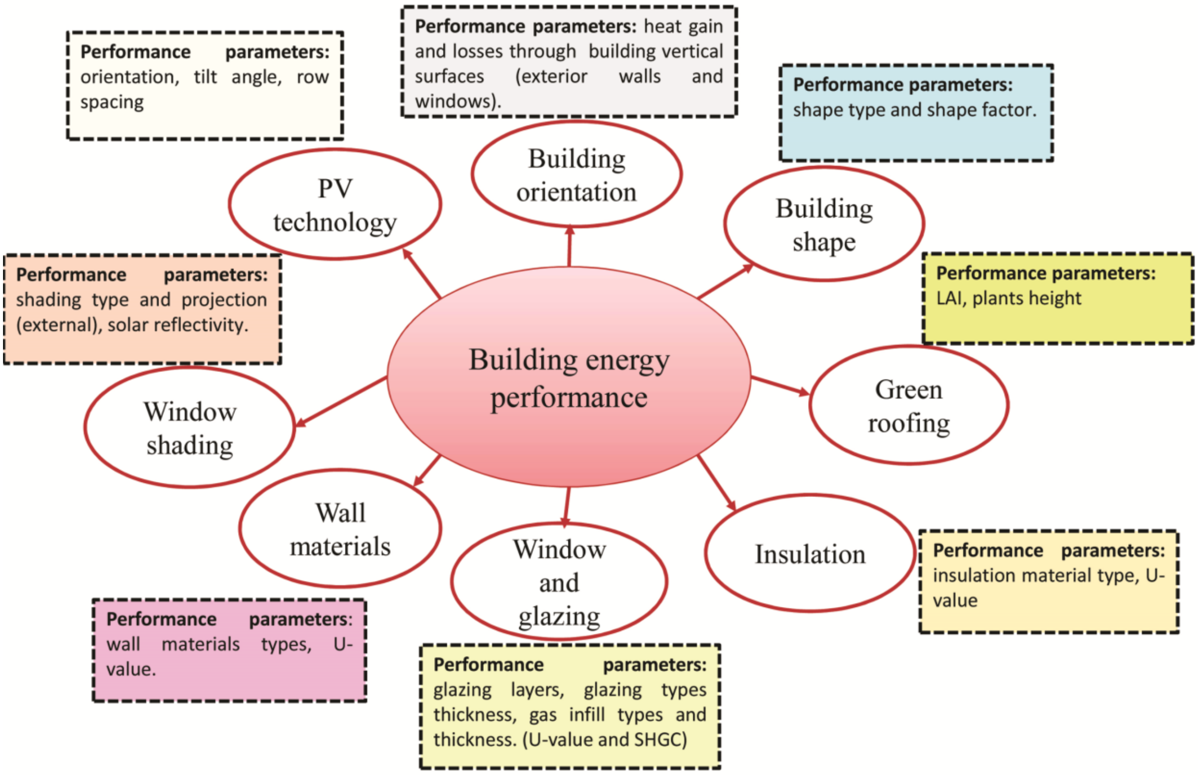
Table 7. The impact of arrays row distance on PV performance

Row distance between PV arrays	PV array area (m2)	Electricity generated (KWH)	Electricity generated/electricity consumed (%)
0.5	5.84	2113.21	13.64
1		2118.07	13.68
1.5		2121.41	13.70
2		2123.72	13.71
2.5		2123.77	13.71

There are no remarkable energy generation differences for the simulated PV arrays, when the row distance increases from 2m to 2.5m. This is mainly due to negligible effect caused by the self-shading of the modules. Thus, distance of 2m between the PV arrays is the most efficient one for the energy generation and mutual shading avoidance. Consequently, PV system makes the best performance at orientation facing south, tilt angle of 30 degrees and row distance equal to 2m.

Overall, research on the first case study helped to specify measures for each factor in Figure 2, in relation to the factors. Figure 5 shows the measures/parameters for each factor needed for performance based design and optimization.

Figure 5. Key factors and measures for building performance analysis



5. CASE STUDY 2: THE ECOLOGICAL (PASSIVE HOUSE) BUILDING

While the focus in the case study 1 was on the design optimization process and renewable technology implementation, the second case study, the Gaziantep Ecological building, which was built by the local authority with Gaziantep, addresses the development of the other two components of the conceptual framework: These are design rules and the local energy performance assessment scheme. Figure 6 shows the building itself and its BIM model.

Figure 6. Ecological building and its BIM model

5.1. Findings from Case Study 2 (The Ecological Passive House Building)

Two design facets namely energy conservation and material conservation are considered in grouping the factors in Figure 6 in the development of the design rules for effective decisions for building design and ensuring compliance to ecological design measures. Table 8 presents the design factors that are considered for examining the building energy performance. Each of the design factors in Table 8, is analysed with its possible alternatives

Table 8. Grouping the design factors in energy performances facets

Building energy performance facets	Design Factors
Energy conservation (EC)	Effective direction of the building form (EC 1)
	Design of Geometric Building Form (EC 2)
	Green roof application (EC 3)
	Effective use of PV (EC 4)
Material conservation (MC)	Proper and efficient insulation materials (MC 1)
	High Performance Glass (MC 2)
	Efficient wall material (MC 3)
	Effective shading (MC 4)

5.1.1. Effective Direction of the Building Form (EC1)

As part of the building design, the orientation of building should be considered. This was deeply studied within the first case study (the ARBIM building). The results showed that when locating the building in the east-west axis, where the long length walls are facing the south-north direction and the bigger glaze area stored on the walls facing south direction, the building performed the best in terms of energy performance.

5.1.2. Design of Geometric Building Form (EC2)

A rectangular building shape is adopted in ecological building design. However, as mentioned by Pacheco et al. (2012), there are different parameters related building shape, which may impact the cooling and heating energy consumption. Amongst these parameters is the shape factor, which is the ratio of the length to the width of the building. The significance of this parameter is always measured along with building orientation. The shape factor of ecological building is equal to 2.1. Table 9 shows the impact of different building shape on the building energy performance.

Table 9. The impact of building shape on building energy performance

The length added to south-north direction	X, Walls in north-south. (m)	Y, Walls in east-west. (m)	Shape factor X/Y	Cooling energy load (KWh)	Heating load (KWh)	Total energy load (KWh)
0	10.00	10.00	1.00	1901.94	927.78	2829.72
10%	11.00	9.091	1.21	1858.57	911.52	2770.09
20%	12.00	8.333	1.44	1794.93	917.29	2712.22
30%	13.00	7.692	1.69	1789.17	893.12	2682.29
40%	14.00	7.143	1.96	1788.80	865.59	2654.39
45% (Actual)	14.5	6.896	2.102	1796.89	851.89	2648.78
50%	15.00	6.667	2.25	1805.7	836.93	2642.63
60%	16.00	6.250	2.56	1833.01	801.37	2634.38
70% (optimal)	17.00	5.882	2.89	1820.62	795.68	2616.3
80%	18.00	5.556	3.24	1857.55	766.01	2623.56
90%	19.00	5.263	3.61	1905.62	736.72	2642.34
100%	20.00	5.00	4.00	1952.46	706.53	2658.99

Minimum energy load is achieved when the shape factor is equal to 2.89, making an annual energy consumption of 2616.3 KWh. This means that, the proportion of the wall length in the north south direction to the wall length on the east-west direction has to be 2.89. The results also indicate that square building shape performs relatively worse in energy consumption. As a result, a rectangular building shape with shape factor of 2.89 is the best decision as it leads to the best efficient energy performance.

5.1.3. Green Roof Application (EC3)

Green roofs are key to provide the building with less energy use and CO_2 emission. The parameters affecting the performance of green roofs are: the plants height and Leaf Area Index (LAI) (Vera et al., 2015). LAI is the percentage of the leaves surface to the transpiring parts of plants and soil layer below. The impact of the plants height and LAI on the building energy performance is studied. This would help to understand the effects of these parameters to achieve the best possible benefits of green roofs based on selections of green roof systems.

Three types of green roof are considered for studying and simulating their impact on building energy performance. These are: Extensive, Intensive and Semi Intensive green roofs. Each one of them has different characteristics in term of plant height and LAI and soil thickness. Table 10 shows the impacts of the three types of green roof systems on building performance.

Table 10. The impact of green roofing type on building energy performance

Green roof type	Cooling energy consumption (KWh)	Heating energy consumption (KWh)	Total energy consumption (KWh)
No green roof	7604.46	5296.89	12901.35
Extensive (LAI =2, height =0.1m)	7460.32	5052.11	12512.34
Semi intensive (LAI=2.5, height= 0.3m)	7302.95	5111.90	12414.85
Intensive (LAI= 4, height= 0.8)	7159.34	5190.36	12349.7

All types of green roofs systems lead to reduce both cooling and heating energy consumption compared to conventional roof system. The intensive roof system performs the best when compared to extensive and semi intensive green roofs. This is mainly due to the plant height and LAI, which increase shading and decrease the solar heat gain and subsequently decreases the cooling energy load.

5.1.4. Effective Use of Photovoltaic (PV) Panels (EC4)

This method was deeply studied within the first (ARBIM building) case study. It was done by exploring the design process steps needed to design PV modules using Design Builder and studying the impact of performance parameters (PV orientation, PV tilt angle, and PV row spacing) on the energy generation of PV modules. The results showed that using PV with orientation facing south, tilt angle of (30°) degree and row spacing not less than (1.5m), have the best performance in energy generation.

5.1.5. Preventing Heat Loss via Proper Insulation Materials (MC1)

The insulation of building envelopes makes a great contribution to the building energy performance. Four main types of insulation materials are considered for both exterior walls and roofs. These are Extruded Polystyrene (XPS), Expanded Polystyrene (EXP), Rock Wool (RW), and Glass Wool (GW). Table 11 and Table 12 show respectively the impact of the wall and roof insulations on building energy performance.

Table 11. The impact of wall insulation on building energy performance

Insulation type	U- value (W/m2. k)	Cooling energy consumption (KWh)	Heating energy consumption (KWh)	Total energy consumption (KWh)
Extruded polystyrene (XPS)	0.096	7278.93	5027.70	12306.63
Expanded polystyrene (EXP)	0.127	7319.62	5207.64	12527.26
Rook wool (RW)	0.148	7352.46	5306.22	12658.68
Glass wool (GW)	0.112	7302.95	5111.9	12414.85

The results confirmed that Extruded Polystyrene (XPS) is the best type for insulation (Table 11). This analysis was carried out for the roof insulation and extruded polystyrene is also the best insulation material for the roof as shown in Table 12. However, there was no insulation used for the roof in the building.

Table 12. The impact of roof insulation on building energy performance

Roof insulation type	U- value (W/m2. k)	Cooling energy consumption (KWh)	Heating energy consumption (KWh)	Total energy consumption (KWh)
Extruded polystyrene (XPS)	0.087	7302.95	5111.9	12414.85
Expanded polystyrene (EXP)	0.112	7331.38	5269.82	12601.20
Rook wool (RW)	0.128	7333.22	5394.45	12727.67
Glass wool (GW)	0.1	7332.98	5187.78	12520.76

5.1.6. High Performance Windows (MC2)

Windows are important elements in buildings as it greatly eliminates the overall energy use of buildings. The parameters impacting on window performance are as follow: the glazing layers, thickness and the gas infill type and thickness (Karasu, 2010). Firstly, three types of window system including, triple, double and single glazing with two different thicknesses (4mm-6mm) are analysed and simulated. Table 13 shows the impact of different window system on building energy performance.

Table 13. The impact of window glazing types on building energy performance

Glazing type	U-value (W/m2. k)	SHGC	Cooling energy load (KWh)	Heating energy load (KWh)	Total energy load (KWh)
Triple 4mm low e- 16 mm argon (actual)	0.852	0.395	7302.95	5111.90	12414.85
Triple 6mm low e- 16 mm argon (optimum)	0.849	0.383	7172.66	5218.44	12391.1
Double 4mm low e- 16 mm argon	1.896	0.469	8647.05	4774.71	13421.76
Double 6mm low e- 16 mm argon	1.881	0.458	8493.34	4855.65	13348.99
Single low e 6 mm	3.162	0.468	8532.65	5286.21	13818.86
Single low e 4mm	3.184	0.468	8506.16	5276.92	13783.08

The use of triple glazing system has the best performance in energy performance when compared to the double and single glazing systems. Thickness also plays a key role in decreasing the amount of energy used by the building, in which 6mm glaze lead to less energy consumption when compared to 4mm glaze window.

The type of gas infill gap is analysed. Table 14 presents the impact of the gas type on building performance. From Table 14, xenon gas infill, which has well thermal properties, leads to efficient energy performance compared to argon and air gas infill. The rank of the gas types from best to less impact on energy performance are: xenon, argon, and air gas infill.

Table 14. The impact of gas infill type on building energy performance

Gas infill type	U- value (W/m2. k)	SHGC	Cooling energy load (KWh)	Heating energy load (KWh)	Total energy load (KWh)
16 mm argon (actual)	0.852	0.395	7302.95	5111.90	12414.85
16 mm air	1.045	0.402	7383.19	5194.94	12578.13
16 mm xenon (optimum)	0.718	0.390	7293.09	5072.38	12365.47

Finally, the impact of gas infill thicknesses on building energy performance was simulated. Table 15 shows the impact of different gas thickness on building energy consumption. The thickness of gas infill has impact on the building energy performance: as the layer thickness decreases, the energy consumed by the building increases. This is mainly due to increase in the U-value and SHGC (Solar Heat Gain Coefficient) leading to escalation in cooling and heating energy consumption.

Table 15. The impact of gas infill thickness on building energy performance

Gap thickness	U- value (W/m2. k)	SGHC	Cooling energy consumption (KWh)	Heating energy consump. (KWh)	Annual energy consump.(KWh)
16 mm	0.852	0.395	7302.95	5111.90	12414.85
13 mm	0.935	0.396	7310.15	5159.80	12469.95
10 mm	1.1	0.401	7353.44	5219.95	12573.39
6mm	1.490	0.412	7420.91	5385.23	12806.14
4mm	1.867	0.420	7453.65	5560.71	13014.36

Rank of the impact of gap thickness from best to least be as follows: 16 mm, 13, mm, 10mm, 6mm, and finally 4mm. Based on the analysis on the window system types, including the window types and thicknesses, gas infill types and thickness, the best window system to be used in building design is triple 6mm low e glazing and 16mm xenon gas infill gap.

5.1.7. Appropriate Wall Materials Selection (MC3)

The ecological building exterior walls were designed with reinforced concrete using ecological building material such as gas concrete, obtained from facilities located in Gaziantep and nearby. However, this construction method is not widely applicable especially for large and multistorey buildings due to its excessive cost. Therefore, other types of wall materials locally used, are taken into consideration for analysis to measure their impacts on building energy consumption together with the actual type used in the ecological building.

Table 16 shows the impact of different wall construction system on building energy performance. The AAC block is the most efficient material for walls as the lower energy consumption is achieved via comparison with the other materials. This is mainly due its lower U-value, ensuring lower heat loss through walls and lower energy consumption is achieved.

Table 16. The impact of wall material type on building energy performance

Wall type	U- value (W/m2. k)	Cooling energy consumption. (KWh)	Heating energy consumption.(KWh)	Total energy consumption. (KWh)
Reinforced concrete (actual)	0.112	7386.10	5264.98	12651.08
Autoclaved aerated concrete block	0.094	7416.82	5016.71	12433.53
Brick aerated	0.105	7455.99	5199.62	12655.61
Concrete block	0.108	7431.07	5217.46	12648.53

The reinforced concrete wall is also efficient as the gas concrete is used, which works as a heat insulator too. However, the AAC block is recommended.

5.1.8. Effective Window Shading Design (MC4)

Appropriate collection of shading device is vital for efficient energy and building comfort conditions. The shading element changes the amount of reflected and diffused solar radiation striking the openings of the building. Analysis is conducted for two types of shading: i) internal shading and ii) local shading separately. For internal shading, three types are studied. These are: i) slatted blind with high reflectivity, ii) diffusing blind-shade roll and iii) drapes close weave light. Table 17 shows the results of internal shading impact on building performance.

Table 17. The impact of internal shading type on building energy performance

Window shading type	Cooling energy consumption (KWh)	Heating energy consumption (KWh)	Total energy consumption (KWh)
No shading	7302.95	5111.90	12414.85
Slatted blind- high reflectivity	7036.14	5110.12	12146.26
Diffusing blind – shade roll	7338.85	5110.84	12449.69
Drapes close weave	7087.99	5110.79	12197.78

In Table 17, the slatted blind with high reflectivity is the best choice for internal shading that reduces the cooling load by 266.81 KWh compared to non-shaded window. The use of diffusing blind shade roll type is not recommended as it increases the cooling energy use. . Table 18 shows the impact of external window shading on building energy performance.

Table 18. The impact of external shading on building energy performance

Shading type	**Cooling energy consumption (KWh)**	**Heating energy consumption (KWh)**	**Total energy consumption (KWh)**
No shading (actual)	7302.95	5111.90	12414.85
Overhang (0.4 m)	6617.03	5498.31	12115.34
Overhang (0.5 m)	6432.66	5604.8	12038.46
Overhang (0.75 m)	6174.03	5853.24	12027.27
Fin (0.4 m)	6989.77	5322.81	12312.58
Fin (0.5 m)	6921.22	5379.34	12300.56
Fin (0.75m)	6839.87	5494.49	12334.36
Overhang (0.5 m + fin 0.5) (optimum)	6106.27	5884.07	11990.34

For local (external) shading, the simulated types are overhang with different projection (0.4, 0.5, 0.75) m, Fin shading with different projection (0.4, 0.5, 0.75) m, and overhang and fin with projection of (0.5) m. Each one of them are analysed separately and their impacts on the cooling and total energy consumption are calculated. The combination of overhang and fin with projection of (0.5m) led to less cooling consumption and less total energy consumption when compared to the other types of shading.

5.2. The Design Rules Identified from Case Study 2 Reflecting the Local Values

After conducting a comprehensive study about the building design strategies in relation to the design factors and examining different design parameters by analysing and simulating their impacts on building energy performance, design rules are specified for the implementation of the performance based design factors. The design rules are presented in Table 19.

Table 19. Building design rules and ontology for performance based design

Design Facets	**Design Factors**	**Design Rules**
Energy conservation (EC)	Effective direction of the building (EC 1)	Long length walls should be facing north-south orientation (EC 1.1)
		Bigger glaze area should be facing south orientation (EC 1.2)
	Using simple geometric design (EC 2)	Rectangular shape (EC 2.1)
		Shape factor = 2.89 (EC 2.2)
	Green roof application (EC 3)	Intensive green roof, (LAI= 4, plant height= 0.8) (EC 3.1)
	Proper use of photovoltaic (PV) (EC 4)	Orientation- south (EC 4.1)
		Tilt angle= 30 (EC 4.2)
		Raw spacing $\geq$ 2 (EC 4.3)
Materials conservation (MC)	Preventing heat loss by choosing proper insulation materials (MC1)	Extruded polystyrene XPS for roof (MC 1.1)
		Extruded polystyrene XPS for wall (MC 1.2)
	High performance window (MC2)	Window system-triple window (MC 2.1)
		Glazing type- low e coating (MC 2.2)
		Glaze thickness- 6mm (MC 2.3)
		Gap infill type- xenon, and gap thickness-16 mm (MC 2.4)
		Window gap thickness-16 mm (MC 2.5)
	Efficient wall material (MC 3)	Autoclaved aerated concrete (AAC) (MC 3.1)
	Effective shading (MC 4)	Window shading- slatted blind (MC 4.1)
		Local shading- overhang and fin of (0.5m) projection (MC 4.2)

Following these rules, efficient and sustainable design can be achieved. Thus, less energy for both heating and cooling is consumed, which in turn would lead to less CO_2 emission.

5.3. Local Energy Performance Assessment Scheme for Design Solutions

A local energy performance evaluation scheme is developed to determine the success of the building design performance, following the developed rules in the previous section (Table 19). The local energy assessment scheme is based on the goal of scoring method. The scoring method will undertake the established rules as an evaluation measure to the building design. Based on the analysis results of the design rules, four scale scoring levels are adopted to identify the level of implementation of these rules as shown in Table 20. Three points are given for successful implementation, two points for average implementation, one point for poor implementation and zero point for non-implementation.

Table 20. The evaluation scoring scale

Points (*)	Implementation status of design rules
0	Not implemented
1	Un successful implementation
2	Average successful implementation
3	Successful implementation

For evaluating and assessing the actual building design, the scoring scale is used to grade each design parameters used in the building. This is via comparing the design decision made in the actual building with the design rules presented in Table 19. The local energy performance assessment scheme for the assessment of the actual building is shown in Table 21.

Table 21. The local energy performance assessment scheme for the Ecological building

Local Energy Performance Assessment Scheme							
	Rules based building design		Points (*)		Rules based building design		Points (*)
Energy conservation (EC)	Orientation EC1	EC 1.1	2	Material conservation (MC)	Insulation (MC1)	MC 1.1	3
		EC 1.2	2			MC 1.2	2
	Building form (EC2)	EC 2.1	3		External window (MC2)	MC 2.1	3
		EC 2.2	2			MC 2.2	3
	Green roof (EC3)	EC 3.1	2			MC 2.3	2
	PV technology (EC4)	EC 4.1	3			MC 2.4	2
		EC 4.2	3			MC 2.5	3
		EC 4.3	3		External wall (MC3)	MC 3.1	2
					Window shading (MC4)	MC 4.1	3
						MC 4.2	-
Total point achieved			20	**Total point achieved**			23
Section points			24	**Section points**			30
Success level %			83	**Success level %**			77
Total success = 80%							

This assessment scheme is divided into two sections, each section encapsulates important and effective design factors that should be considered in the building design. There are 3 points available for each design rules. Accordingly, the total points that could be achieved in both energy conservation section and material conservation section are equal to 24 and 30 points respectively. Thus, the total points available in the assessment scheme are equal to 54 points.

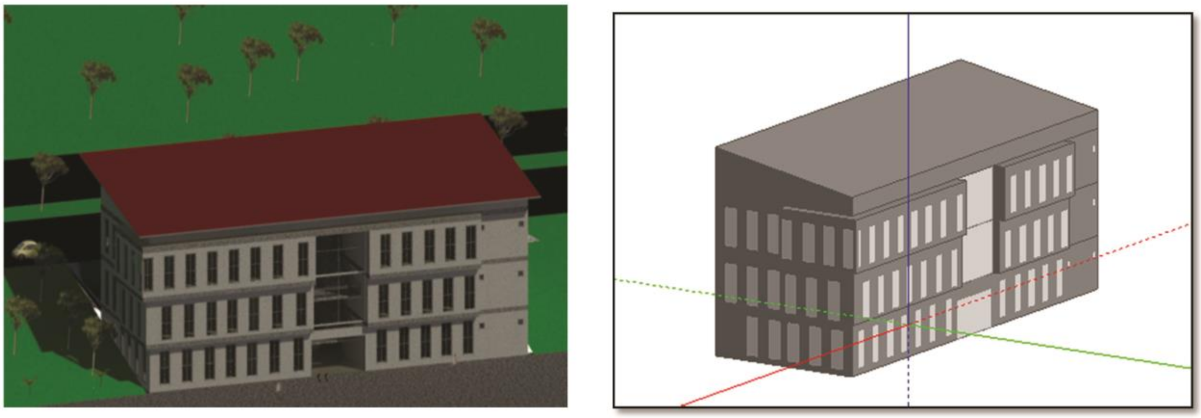
By using the evaluation scoring scale presented in (Table 20), a mark point is given to each design parameters based on their implementation in the actual building design and the rank of simulation results for each one on them. Accordingly, the total point achieved for both energy conservation and material conservation criteria are equal to 20 and 23 points respectively. Then by dividing the points achieved for the actual design by the total points available in the local scheme, the success level in implementing or following the rules-based design is calculated for both energy conservation and materials conservation facets and it is equal to 83% and 70% respectively.

As a result, the building is 80% successful in implementing the design strategies and rules for the building energy performance facets including both energy conservation and material conservation facets. There are five levels considered for the qualification of the building in term of energy efficiency, which are pass (50%-59%), good (60%-69%), very good (70%-79), excellent (80%-89%), outstanding (90%-100%). Therefore, the building design is deemed as excellent in term of energy efficiency.

6. CASE STUDY 3: THE HEALTH CENTRE BUILDING

The third case study, is the health science building in the Hasan Kalyoncu University campus. It is a three-storey university building. Figure 7 shows the BIM model of the building.

Figure 7. BIM model of the Health Science Building



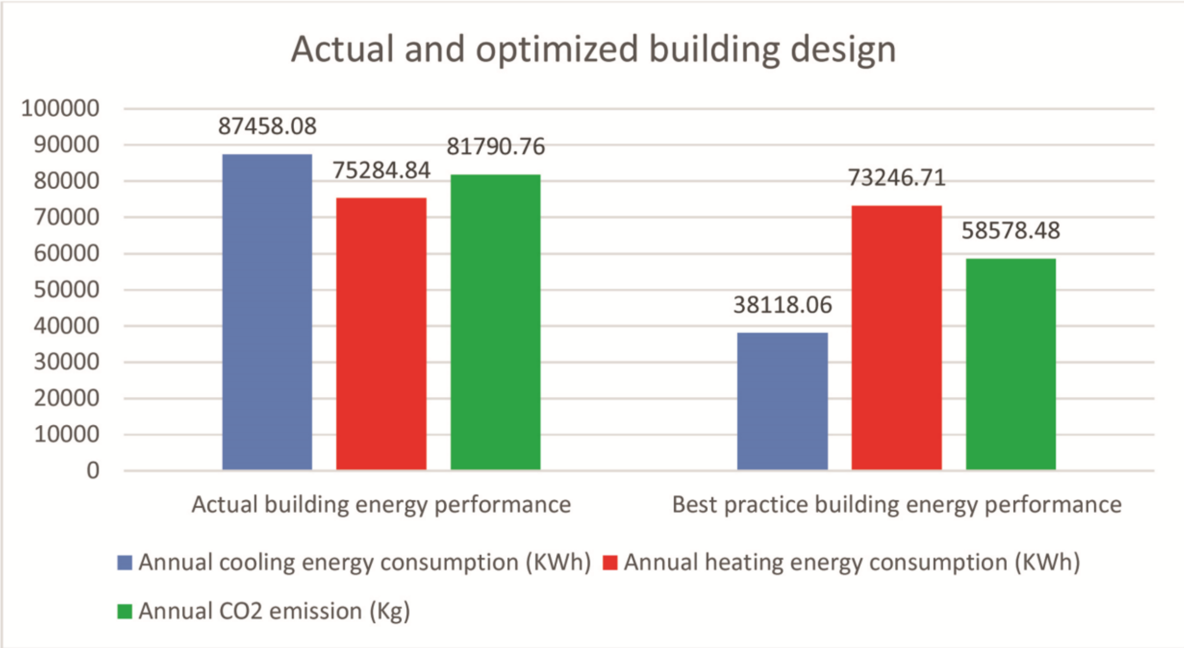
6.1. Findings from Case Study 3: The Health Centre Building

The overall BIM based design and optimization framework is validated on a real building case study building. This is done in three stages; these are i) building design process, ii) building design optimization, and iii) finally building design evaluation with the proposed local energy performance assessment scheme. In the first stage, following the developed BIM based design process, which reflects a collaborative nature of design between the stakeholders as shown in Figure 4, a 3D building model was produced by using the BIM by the architects and shared with the energy expert using the performance analysis and calculate the actual building energy performance and share the outcomes with the other stakeholders.

In the second stage, the actual building design is optimized by adopting the developed design rules related building design parameters and PV technology (Table 19). This is to estimate the amount of energy that could be saved when adopting these design decisions in the early design stage and compare it with the actual design performance.

Figure 8 presents both the actual and the optimized building energy performance. The best design decisions regarding building design parameters led to a significant energy saving when compared to the actual building design. The cooling energy consumption is deceased by 56% from 87458.08 KWh to 38118.06 KWh, the heating energy consumption is decreased by 3% from 75284.84 KWh to 73246.71 KWh, and finally the CO_2 emission is also reduced by 28% from 81790.76 Kg to 58578.48 Kg. As a result, the total amount of KWh that could be saved for both heating and cooling are 51378.15 KWh for a year.

Figure 8. The actual and optimized building performance for the Health Science Building



Finally, to assess the energy performance of the building design, we first used the evaluation scoring scale to grade each design parameters used in the building (see Table 20). Thus, based on the results and the ranks of the simulated parameters and their alternatives in energy performance, the level of success in implementing these rules is determined. Accordingly, a mark point is given to each one of them. Once the level of success in implementing the design rules for each design parameter is determined, the local energy assessment scheme is used to calculate the overall performance of the building design.

Table 22 shows the local energy assessment scheme and the points given for the actual building design. Energy conservation facet (EC), design factors are: effective direction of the building (EC1), use simple geometric design (EC2), green roof application (EC3) and proper use of PV technology (EC4).

Table 22. The evaluation of the actual building performance for the Health Science Building

Local Energy Performance Assessment Scheme							
Energy conservation (EC)	**Rules based building design**		**Points (*)**	**Material conservation (MC)**	**Rules based building design**		**Points (*)**
	Orientation EC1	EC 1.1	1		Insulation (MC1)	MC 1.1	2
		EC 1.2	1			MC 1.2	0
	Building form (EC2)	EC 2.1	3		External window (MC2)	MC 2.1	2
		EC 2.2	2			MC 2.2	1
	Green roof (EC3)	EC 3.1	0			MC 2.3	2
		EC 4.2	2			MC 2.4	1
		EC 4.3	3			MC 2.5	2
					External window (MC3)	MC 3.1	3
					Window shading (MC4)	MC 4.1	2
						MC 4.2	0
Total point achieved			14	**Total point achieved**			15
Section points			24	**Section points**			30
Success level %			58	**Success level %**			50
Total success = 54 %							

The rules EC 2.1, EC 3.1, and EC 4.3 were implemented successfully, and then 3 points are awarded for each one. EC 2.2, EC 4.1, and EC 4.2, and EC were implemented with average success, accordingly 2 point are given to each one. EC 1.1 and EC 1.2 were poorly implemented; thus 1 point is given to each one. EC 2.2 refers to the shape factor and it should be equal to 2.89 while the shape factor of the actual building design is equal to 2.69. EC 4.1 refers to orientation of PV panels and it should be at south orientation while the orientation of the actual PV design is facing south-west orientation. EC 4.2 refers to the tilt angle of the PV panels, and it should be equal to 30, while the actual PV tilt angle is equal to 16.

EC 1.1 and EC 1.2 refers to the building orientation, based on the simulation results the south orientation in which the long length wall facing north-south and bigger glaze area should be facing south orientation is the best decision to make while the actual building orientation is facing south-west orientation. Finally, EC 3.1, which refers to green roofing, is not applied in the actual building, so no point is awarded.

For material conservation criteria, the required methods are: choosing efficient insulation material (MC1), high performance window (MC2), efficient wall construction materials (MC3) and effective shading (MC4). In line to these methods, MC 3.1 were implemented successfully, and then 3 points is awarded to this design method. MC 1.1, MC 2.1, MC 2.3, MC 2.5, and MC 4.1 were implemented with average success, and 2 points are awarded to each one. MC 2.2 and MC 2.4 were poorly implemented; accordingly, 1 point is awarded to each one. Finally, MC 1.2 and MC 4.2 are awarded no points because they are not implemented.

MC 1.1 refers to roof insulation, the type used for actual building roof is rock wool and while the simulation results showed that extruded polystyrene (EXP) is the best type to be used. MC 2.1 refers to the window system type, double glazing is used for the actual design while the simulation results showed that triple glazing has the best performance. MC 2.3 refers to glazing thickness, 4mm glazing is used for the actual building while the simulation results showed that 6mm performs the best in term of energy performance. MC 2.5 refers to window gap thickness, 13 mm gap thickness is used for the actual window design while the simulation results showed that window gap thickness of 16 mm performs the best.

MC 4.1 refers to the internal shading; shade roll is used for the building while the simulation results showed that slatted blind with high reflectivity is better to be used to shade windows. MC 2.4 refers to the gas infill type, the type used for the actual windows is air while the results of analysis shows that xenon is better to be used in windows.

Consequently, the actual building design is 58% successful in energy conservation, and 50% successful in materials conservation. As a result, the building achieves pass with 54 % based on total points considering both energy and material conservation criteria.

The conceptual framework shown in Figure 1 is expanded and detailed as a practical guide for the key stakeholders including clients, architects and engineers for how BIM can be adopted for design and optimization for energy efficiency.

6.1.1. Integrated Design Process Point of View

To achieve sustainable building design, an integrated design process and optimization is needed in the early design stage. An integrated design process modelling is developed for the first component of the conceptual framework depicted in Figure 1 for bi-directional information exchange, shown in Figure 9. During the design stage, different design strategies regarding energy performance could take place including both active and passive strategies. The methods or approaches for information exchange between BIM and energy analysis software are mainly dependent on the purpose of the analysis and what type of information is needed. Yet, transferring the results of analysis back into BIM model is challenging.

Figure 9. Expanded representation of the Process component of the Conceptual Framework

Main components of the framework		Sub-components	Requirements and Tasks	
Component 1	A Design Optimization Process	Stakeholders	Engineers, architects, energy experts, and clients	
		Process stages and tasks	clients	Review building design and alternatives
			Architects engineers	Prepare and check the selected alternatives for energy analysis
			Energy experts	Analyze actual building energy performance and alternatives
			Architects engineers	Review design alternatives with energy performance and cost results
			clients	Final selection and approval of a design alternative
		Data and information exchange requirements	Revit to design builder: export the building model as gbXML	
			Design builder to excel: obtain the energy performance results of the building model	
			Excel to Revit: import the results in Revit to make changes in the building design by using Revit plug in (Excel importer)	

Enabling designers to investigate important design criteria and helping them make informed design decisions and effective rules related to building design criteria including building orientation, building shape, and envelope materials such as (walls, windows, insulation, and shading). Finally, within this concept of integrated environment and information exchange, designers and engineers can adopt principles related to passive designs to create efficient designs considering the local environment conditions for the energy efficient building.

6.1.2. Renewable Technology (PV) Implementation Point of View

It is necessary to include such renewable technologies in the building design so as to generate energy in the buildings while consuming. Thus, three main parameters related to the PV performance in term of electricity generation; these parameters are: PV orientation, PV tilt angle, and PV raw spacing. Figure 10 shows the details of component 2 of the conceptual framework for PV design and installation.

To accurately design the PV modules, the design parameters would lead to optimize PV performance are considered and simulated. Based on our findings, the energy generation of PV modules could be optimized by orientating the PV modules towards South. To maximize the exposure of the modules, tilt angle of 30 will increase the efficiency as well as the energy generation of the PV modules. Finally, when there is more than one PV array, the spacing between them should not be less than 2m.

Figure 10. Detailed view of the Technology component of the Conceptual Framework

Main components of the framework		Sub-components	Requirements and Tasks
Component 2	Technology Implementation (PV Technology)	PV design process by using Design Builder	Geometric model development for the solar PV arrays
			Assigning electrical performance model to the solar PV array
			Creation of PV electrical performance model by using and actual manufacturer specification
			Include electrical load center to model DC-to-AC inverter equipment
		Parameters based PV performance optimization	Proper selection of PV modules orientation by directing them toward south orientation
			Installing the PV modules at tilt angle of 30 degree
			Row spacing between PV arrays should not be less than 2 m

6.1.3. Design Rules Point of View

Ecological building design criteria are capable in achieving the lowest energy requirements (Omrany and Marsono, 2016). Figure 11 shows the details about component 3 of the conceptual framework.

Figure 11. Expanded details of component 3 about design rules and ontologies

Main components of the framework		Sub-components	Requirements and Tasks	
Component 3	Design Rules and Ontology	Rules based design	Building orientation	Long length walls should be facing north- south direction, with bigger glaze facing south
			Building form	Building form should be rectangular with shape factor of 2.89
			Green roof system	Intensive green roof, (LAI= 4, plant height= 0.8)
			PV technology	Same applied in component 2, PV technology
			Insulation materials	The use of extruded polystyrene for both walls and roofs
			Window system	Triple glaze 6 mm- low e- 16 mm xenon gas infill
			Wall materials	Autoclaved aerated concrete block (AAC)
			Shading	Slatted blind for window shading, and (overhang and fin) of 0.5 m projection for local shading

The impact of different passive design strategies on the total building energy performance is investigated. Thus, seven design parameters (building orientation, building shape, insulation materials glazing types and thicknesses, window shading, wall materials, and green roofing) are analysed with its possible alternatives, and the best one in term of energy performance were selected. Thus, a number of best design decisions were identified to decrease in the total energy use in term of cooling and heating energy.

Southern orientation is found to perform the best where the building's long wall with bigger glaze area is facing south. This will help the building to be naturally heated, lighted and less investment for insulation can be achieved.

Rectangular building form with shape factor of 2.89 is found to be the best decision for building shape design. The shape factor plays a significant role in minimizing the exposed area of the building walls, which in turn will lead to less heat losses of the building envelope.

Green roofs are the key to provide buildings with less energy use and CO_2 emission, in which the plants and soil would help for cooling through water evaporation in summer and moisturizing the air, leading to cooling the building naturally. The soil layer would work as insulation layer and reducing the heating energy use of building in winter. The intensive roof system with LAI=4 and height= 0.8m is found to be the best decision for green roofing type.

Wall materials, the use of gas concrete (AAC) block has the best energy performance. Gas concrete is preferred when used for walls as it preserves energy by providing heat insulation. The insulation of building envelopes has the greatest impact on the building energy performance. Extruded polystyrene is the best insulation material for both walls and roofs.

External window, the thermal performance of windows can be determined by two factors, which are the thermal transmittance (U-value), and solar heat gain coefficient (SHGC). These factors determine the amount of heat flow through a window. It is founded that triple window of 6mm low e glazing with 16mm of xenon gas infill type would perform the best. Window shadings (internal and external) can reduce the cooling energy consumption.

6.1.4. Design Performance Assessment Scheme Point of View

Developing an energy performance assessment scheme for buildings considering the local design values and conditions is highly needed and accordingly developed in this research. Figure 12 shows the component 4 of the framework about performance evaluation.

Figure 12. Gives details about component 4 of the conceptual framework

Main components of the framework		Sub-components	Requirements and Tasks
Component 4	A Local Energy Performance Assessment Scheme	A scoring and evaluation scale legend	Determining how successful each developed rule in component 3 are being implemented in building design
		A local energy performance assessment scheme	Assessing and evaluating the building design based on the scoring scale legend, and developed design rules

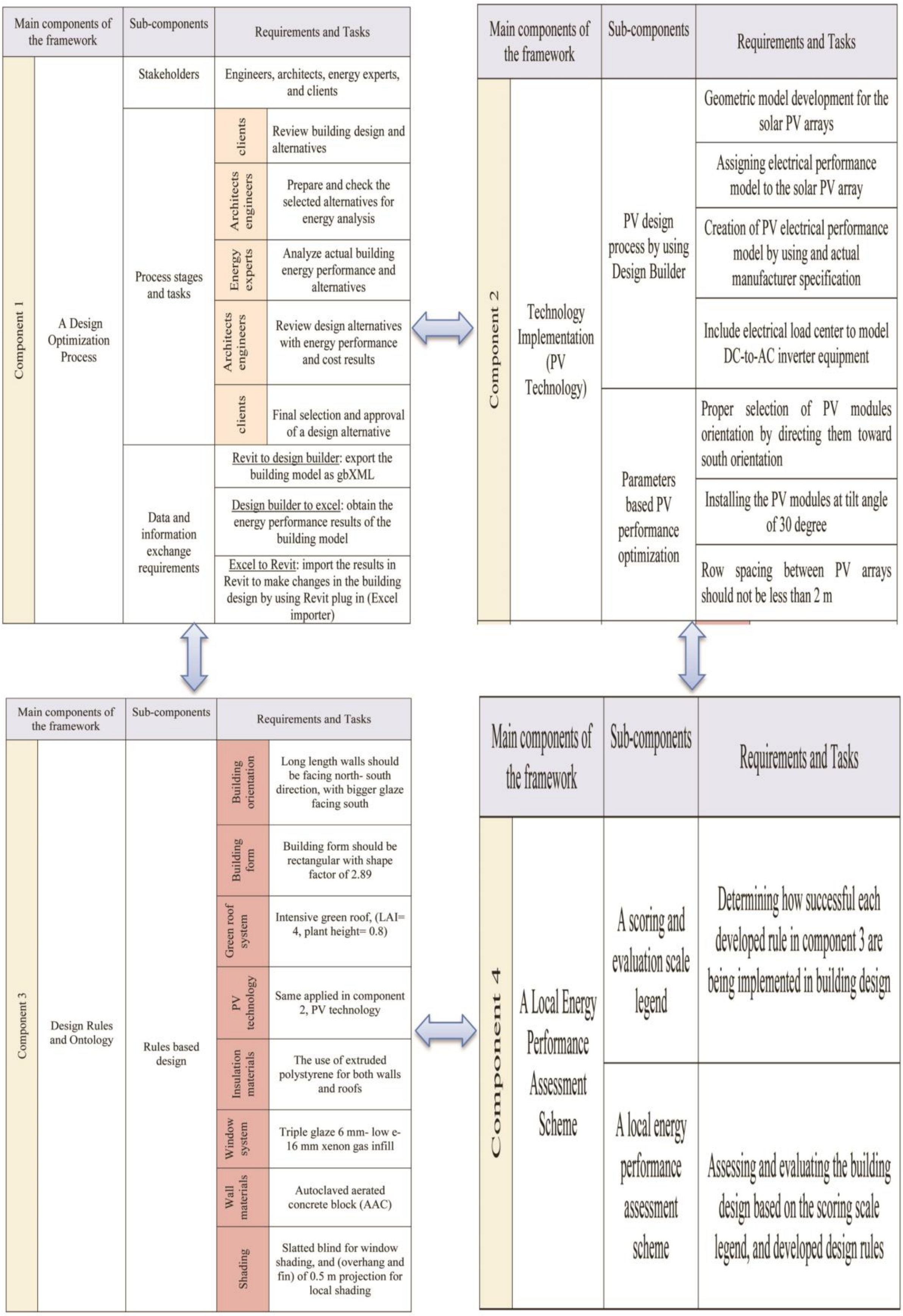
It is asserted that the performance assessment scheme would provide the design team an opportunity to upgrade the building design as it delivers recommendations.

7. CONCLUSION AND RECOMMENDATIONS

In this study, multi case study approach is used for the experimental development of the BIM based design optimization framework. The results showed that the proposed performance-based design framework can help for the best design solutions and decrease the process time required for better design results, which can help designers and engineers to design a sustainable and environmentally friendly solutions.

In Figure 13, the overall BIM based performance-based design framework including both the main and sub-components of the framework is documented, providing all the requirements and tasks needed for proper BIM framework implementation. This framework represents the final outcome that has novelty on its own and can be the response to the research problem through the comprehensive perspective in terms of design optimization process, technology implementation such as PV, design rules reflecting local values, and finally the local energy performance assessment scheme.

Figure 13. The BIM enabled Performance based design framework



Main components of the framework		Sub-components		Requirements and Tasks
Component 1	A Design Optimization Process	Stakeholders		Engineers, architects, energy experts, and clients
		Process stages and tasks	clients	Review building design and alternatives
			Architects engineers	Prepare and check the selected alternatives for energy analysis
			Energy experts	Analyze actual building energy performance and alternatives
			Architects engineers	Review design alternatives with energy performance and cost results
			clients	Final selection and approval of a design alternative
		Data and information exchange requirements		Revit to design builder: export the building model as gbXML
				Design builder to excel: obtain the energy performance results of the building model
				Excel to Revit: import the results in Revit to make changes in the building design by using Revit plug in (Excel importer)

Main components of the framework		Sub-components	Requirements and Tasks
Component 2	Technology Implementation (PV Technology)	PV design process by using Design Builder	Geometric model development for the solar PV arrays
			Assigning electrical performance model to the solar PV array
			Creation of PV electrical performance model by using and actual manufacturer specification
			Include electrical load center to model DC-to-AC inverter equipment
		Parameters based PV performance optimization	Proper selection of PV modules orientation by directing them toward south orientation
			Installing the PV modules at tilt angle of 30 degree
			Row spacing between PV arrays should not be less than 2 m

Main components of the framework		Sub-components		Requirements and Tasks
Component 3	Design Rules and Ontology	Rules based design	Building orientation	Long length walls should be facing north- south direction, with bigger glaze facing south
			Building form	Building form should be rectangular with shape factor of 2.89
			Green roof system	Intensive green roof, (LAI= 4, plant height= 0.8)
			PV technology	Same applied in component 2, PV technology
			Insulation materials	The use of extruded polystyrene for both walls and roofs
			Window system	Triple glaze 6 mm- low e- 16 mm xenon gas infill
			Wall materials	Autoclaved aerated concrete block (AAC)
			Shading	Slatted blind for window shading, and (overhang and fin) of 0.5 m projection for local shading

Main components of the framework		Sub-components	Requirements and Tasks
Component 4	A Local Energy Performance Assessment Scheme	A scoring and evaluation scale legend	Determining how successful each developed rule in component 3 are being implemented in building design
		A local energy performance assessment scheme	Assessing and evaluating the building design based on the scoring scale legend, and developed design rules

The overall framework would impact the design optimization process by allowing the engineers and designers to examine the important design criteria and helping them to make informed design decisions. Changing the design process towards more accurate computation and optimization-based methods in which redefines the roles and responsibilities of design team and help them perform their tasks in a shorter time by adopting effective methods for data and information exchange and making them discover issues during the building design with substantial number of design alternatives very quickly. Many design alternatives can be analysed very quickly in the early design stage. This is due to existence of well-developed design process to identify all the roles and responsibilities of the team members.

The framework also provides opportunities to ensure more efficient building design by adopting renewable energy practices such PV technology. An effective PV system can be designed, which ensures better performance. The framework ensures efficient building design with the design rules related to building performance. Enabling designers to investigate important design criteria and helping them make informed design decisions and effective rules related to building design components including building orientation, building shape, envelope materials such as (walls, windows, insulation, and shading). The traditional design technique has some shortages because this method may contain assumptions based on the rule of thumb which can be incorrect. It may also prefer the aesthetic need without performance analysis. Thus, developed rules in hand may lead to efficient building design, which promises less energy consumption and consequently less environmental impacts.

Finally, the framework proposes a local energy performance assessment scheme, which considers the rules-based building design reflecting the local environment. This local scheme can be vital source of advice as it provides information of how buildings is efficient in energy performance, providing recommendations to enhance building performance for better rating. This was done through developing a scoring scale of four levels, each level set a number of points for how successfully these rules are being implemented in the building design. Then, the created energy assessment scheme, was used to evaluate the building performance.

This research focused on developing a strategic performance-based design and optimization framework for the energy efficient building design. Thus, it is recommended to employ this design approach in the design and construction projects and organizational capacity building as it promises sustainable and ecological design and improved energy performance buildings in Turkey. It is also worth mentioning that the framework developed can be implemented in other places with similar environmental conditions. Finally, the framework developed can be expanded and customized through the inclusion of more connected components or even new user-defined applications within the BIM environment, which could be used as a design tool to inform the efficient building design solutions.

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